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AUTHOR Erikson, George; And Others
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ABSTRACT

Research has suggested that behavioral differences may account for the effects of caffeine on information processing. To investigate the effects of caffeine on memory for supraspan word lists, 107 college students (47 males, 60 females), divided into 12 groups by high and low impulsivity scores on the Eysenck Personality Inventory, participated in the study. The subjects were administered either 0, 2, or 4 milligrams of caffeine per kilogram of body weight. Following a 30-minute absorption period, subjects listened to four word lists presented at a fast rate and four word lists presented at a slow rate. Immediately after the presentation of each word list, oral recall was obtained. An analysis of the results showed that caffeine inhibited females' recall during the slow rate, but not the fast rate. Caffeine had no effect on the recall performance of males. The observed effects of caffeine were not influenced by subjects' typical amount of caffeine consumption, verbal ability, or level of impulsivity. These results suggest that caffeine may impair the effeciency with which females rehearse information in working memory. (Author/BL)

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THE EFFECTS OF CAFFEINE ON MEMORY FOR WORD LISTS

George Erikson

Laurie B. Hager

Chuck Houseworth

Jeff Dungan

Thomas Petros

Bill E. Beckwith

Psychology Department

University of North Dakota

Box 7187, University Station

Grand Forks, North Dakota

58202

CG017810

Address all correspondence to Thomas Petros.

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ERIKSON, G. C., L. B. HAGER, C. HOUSEWORTH, J. DUNGAN, T. PETROS, AND B. E. BECKWITH. The effects of caffeine on memory for word lists.

PHYSIOL. BEH. The present study investigated the effects of caffeine on memory for supraspan word lists. Twelve groups of male and female college students classified as high or low impulsive were administered (p. o.) 0 mg/kg, 2 mg/kg or 4 mg/kg of caffeine. Subjects listened to four word lists presented at a fast rate and four at a slow rate. Caffeine inhibited females' recall during the slow rate, but not the fast rate. Caffeine had no effect on the recall performance of males. The observed effects of caffeine were not influenced by subjects' typical amount of caffeine consumption, verbal ability, or level of impulsivity. The results suggest that caffeine may impair the efficiency with which females rehearse information in working memory.

Key terms: Caffeine, Arousal, Memory, Stimulants

Several studies have recently examined the effects of caffeine on information processing (7, 12, 13). This research has generally shown that the effects of caffeine are dependent upon a subject's typical level of physiological arousal, as indexed by the Eysenck Introversion/Extraversion scale (4). Eysenck (4) argues that behavioral differences between introverts and extraverts are a manifestation of differences in physiological arousal, and given identical conditions of external stimulation, introverts will demonstrate higher levels of physiological arousal than will extraverts. Consequently, the administration of caffeine should result in differential levels of arousal for introverts and extraverts, and result in differences in the efficiency of performance (14).

The results of Gilliland (7) were congruent with the above predictions. Male and female subjects were administered 0, 2, or 4 milligrams of caffeine per kilogram of body weight. The dependent variable was performance on a test of verbal ability that consisted of verbal analogies, antonyms, and sentence completions. Subjects took one form of the test as a pretest, were administered their dose of caffeine, and after a 30 minute absorption period, completed a second form of the test as a posttest. The difference between the pretest and posttest scores constituted the primary dependent variable. Extraverts' performance improved as the dose of caffeine increased, whereas introverts' performance increased between the 0 and 2 mg/kg conditions and then decreased between the 2 and 4 mg/kg conditions. Subsequent work has provided substantial support for the reliability of the introversion/extraversion by caffeine interaction (13). Furthermore, Revelle et al. (13) also found that the interactive effects of trait arousal and caffeine were more clearly and consistently demonstrated when the impulsivity subscale of the introversion/extraversion scale was used to define the subjects' level of trait arousal.

Revelle et al. (13) suggested that caffeine influences the efficiency of information processing. Unfortunately, the specific components or stages of information processing that caffeine influences cannot be determined by the existing data, given the atheoretical nature of the tasks used. The purpose of the present study was to examine the effects of caffeine on memory using a task that has theoretically and empirically discernible component processes. Specifically, the present study assessed whether caffeine selectively influences short or long term memory by examining subjects' immediate memory for word lists (8).

When young adults are asked to recall a list of words in any order they choose, words presented at the beginning and end of the list are recalled better than middle-list items, producing a primacy and recency effect respectively. This pattern of recall is referred to as the serial position effect. The observation that some factors have an effect on only the primacy or recency portion of the serial position curve has been used to support the functional dissociation between short-term memory and long-term memory (8).

The primacy effect is usually attributed to more rehearsal of the initial items of the list while the recency effect is assumed to be due to the quick recall of items still in short-term memory (i.e., items from the end of the list). One purpose of the present study was to examine the influence of caffeine on the shape of the serial position curve, thus examining whether caffeine selectively influences recall from short-term or long-term memory.

If caffeine influences the efficiency of information processing (13), then any factor that influences the efficiency of processing a word list should modulate the extent of any caffeine differences observed. Rate of presentation influences the efficiency of processing a word list with faster rates selectively impairing recall from the primacy but not the recency portion of the serial position curve (3). Therefore, subjects in the present study heard word

lists presented at two different rates to examine the size of any effects of caffeine as a function of the rate of presentation.

METHOD

Subjects

One hundred and seven university students (47 males and 60 females) served as participants. These students were recruited from Introductory Psychology sections and received extra course credit for their participation in this experiment.

There were twelve groups of subjects. Four groups received 0 milligrams of caffeine per kilogram body weight, four groups received 2 mg/kg of caffeine, and four groups received 4 mg/kg of caffeine. Within each dose, subjects were classified as low or high impulsives based upon the median score of the impulsivity subscale of the Eysenck Personality Inventory (Mdn = 4.5). The groups divided according to impulsivity and caffeine were further divided according to sex (see Table 1).

Materials

The stimulus materials consisted of nine lists of twelve, concrete, high frequency nouns (words 40 occurrences per million words). These words were chosen from the Kuchera and Francis Word Frequency Norms (11), such that the lists were matched for frequency and for the number of syllables. The mean frequency for each word list ranged between 144.83 and 138.92. The number of syllables per word ranged from one to three syllables, while the mean number of syllables per word list ranged from 1.60 to 1.42.

Each of the nine words lists (eight test lists and one practice list) was recorded on cassette tape at one word a second (fast rate) and one word every three seconds (slow rate).

The Eysenck Personality Inventory (EPI) was used to classify subjects as either high or low impulsives (13). Furthermore, a Caffeine Consumption

Questionnaire was administered in order to estimate the subject's habitual level of caffeine consumption.

Procedure

In order to control for diurnal variations in arousal (13), all experimental sessions began between 8:00 a.m. and 12:00 p.m. Subjects were asked to get at least five hours of sleep the night before their experimental appointment. Also, they were asked not to consume any caffeine for six hours prior to the experiment.

When subjects arrived, their blood pressure was taken, and they were dismissed from the experiment if it was greater that 140/90 or if they reported any history of hypertension, epilepsy, ulcers, migraine headaches, and/or kidney disorders.

When the screening was finished, each subject completed the FPI, the vocabulary subtest of the Wechsler Adult Intelligence Scale, and the Caffeine Consumption Questionnaire. After completing these questionnaires subjects were administered 0, 2, or 4 mg of caffeine per kg. of body weight dissolved in six ounces of an orange flavored breakfast drink (Tang). Following the ingestion of their drink, a 30 minute absorption period occurred since caffeine reaches the peak blood plasma levels 30 minutes after oral administration (14).

After the 30 minute absorption period, each subject was presented with one practice list and eight experimental lists. Immediately, after each list was presented, oral recall was obtained. Each successive two test lists were defined as one level of practice, thus creating four levels of practice. Within each level of practice, one list was presented at a fast rate and one at a slow rate. For the experimental lists, each specific list and rate of presentation occurred equally often in each of the eight ordinal positions.

RESULTS

A 3 (Caffeine) x 2 (Sex) x 2 (Impulsivity) ANOVA was performed on the

impulsivity scores, WAIS raw and scaled vocabulary scores, and the subjects' habitual amount of daily caffeine consumption (Caffeine Consumption), in order to determine whether the groups differed on these measures. No significant effects were observed in the analysis of the raw or scaled vocabulary scores. The subject's typical level of caffeine consumption was assessed through the administration of a self report Caffeine Consumption Questionnaire. The questionnaire assessed the type and amount of substances consumed that contain caffeine. A caffeine consumption score was computed for every subject by consulting a listing of the approximate amount of caffeine found in various substances (9). The analysis of the caffeine consumption scores revealed a significant main effect of sex, F (1, 106) = 8.5, $p < .01$ with females reporting a higher daily consumption rate (M = 327 mg) than males (M = 167 mg). Finally, the analysis of the impulsivity scores revealed a significant caffeine x impulsivity x sex interaction, F (2, 95) = 5.06, $p < .01$. This interaction revealed sex differences in impulsivity scores that depended on the dose to which subjects were assigned (see Table 1). Therefore, since sex differences occurred for impulsivity scores and caffeine consumption scores, all further analyses were done separately for males and females.

The proportion of words recalled from the primacy (first four words), middle (middle four words), and recency (last four words) portion of each list was computed. A 3 (Caffeine) x 2 (Impulsivity) x 4 (Practice) x 2 (Rate) x 3 (Serial Position) ANOVA was performed separately for males and females. All subsequent tests utilized Newman-Keuls procedures, with alpha set to .05.

Males

Significant main effects of rate, F (1, 41) = 44.55, $p < .01$, and serial position, F (2,82) = 51.08, $p < .01$, were observed along with a significant rate x serial position interaction, F (2, 82) = 17.82, $p < .01$. A subsequent analysis of this interaction indicated that recall declined under the fast rate

at the primacy and middle portions of the curve but not at the recency portion, although serial position effects were obtained at both rates of presentation. A main effect of practice, F (3, 123) = 4.32, $p < .01$, indicated that recall increased significantly between the first and second level of practice, but did not increase over the last three levels of practice.

A 3 (Caffeine) x 2 (Impulsivity) ANOVA was computed on the male's WAIS raw and scaled vocabulary scores, body weight, caffeine consumption score, and impulsivity score (0-9). No significant effects were observed in any of these analyses. Therefore, the analysis of the recall date was not confounded with any of these measures of individual differences.

Females

A main effect of rate, F (1, 54) = 127.09; $p < .01$, serial position, F (2, 108) = 93.13, $p < .01$, and a rate x serial position interaction, F (2, 108) = 44.1, $p < .01$, were observed. Subsequent tests of this interaction indicated that the fast rate impaired recall for the primacy and middle portions of the curve, but had minimal effect on recall for the recency portion of the serial position curve. Also, a main effect of practice, F (3, 162) = 9.26, $p < .01$, and a practice x serial position interaction, F (6, 324) = 2.73, $p < .02$, indicated no practice effects for the primacy and recency portions of the curve, but for the middle portion of the curve, recall increased across practice with some reversal for level 2 and 3 stages of practice (see Table 2).

A significant caffeine x rate interaction, F (2, 54) = 3.80, $p < .03$, was also observed and is displayed in Table 3. Subsequent tests indicated no caffeine effects were observed under the fast rate of presentation while the 2 mg/kg and 4 mg/kg dose impaired recall relative to the 0 mg/kg dose under the slow rate of presentation. An examination of the pattern of means indicates that under the placebo condition, there was a 33% increment in performance during the slow rate, while there was a 19% increment in performance at the 2

mg/kg condition and a 22% increment in performance at the 4 mg/kg condition.

A 3 (Caffeine) x 2 (Impulsivity) ANOVA computed on the female's WAIS raw and scaled vocabulary scores, their weight, caffeine consumption score, and their impulsivity score (0-9) revealed no significant effects. Therefore, the above recall effects were not confounded by any of these measures of individual differences.

The above analysis indicated that caffeine influenced the recall of females but not males. Unfortunately, females reported consuming significantly more caffeine than males. However, when an independent group of 26 males and 52 females completed the caffeine consumption questionnaire, females reported a higher daily consumption rate (M = 166 mg) than males (M = 149 mg), but the difference was not significant ($t < 1.00$). Although the sex difference in reported caffeine consumption was not reliable, we examined whether reported caffeine consumption differences were related to recall differences and would modulate the effect of caffeine on recall. Therefore, males and females within each dose level were divided into high caffeine consumers (subjects who typically consume more than 150 mg of caffeine daily) and low caffeine consumers (subjects who habitually consume less than 150 mg of caffeine daily.) A 3 (Caffeine) x 2 (Caffeine Consumption) x 4 (Practice) x 2 (Rate) x 3 (Serial Position) ANOVA was performed separately for males and females on the proportion of words recalled.

The analysis of the males' data revealed the same significant effects observed in the previous analysis, in addition to a significant main effect of Caffeine Consumption, F (1, 41) = 5.51, $p < .03$. Males who habitually consumed low amounts of caffeine recalled more words (M = .572) than did males who typically consumed higher amounts of caffeine (M = .517). Furthermore, a Pearson product moment correlation computed between Caffeine Consumption and recall was -.22 (p. = .147).

A similar analysis of the females' data revealed the same significant effects observed in the previous recall analysis. Although no significant effects of caffeine consumption were observed, females who habitually consume low amounts of caffeine recalled more words ($\underline{M}$ = .617) than females who report higher levels of caffeine consumption ($\underline{M}$ = .582). Furthermore, the correlation between Caffeine Consumption and recall in the female data was -.20 (p = .128).

A final analysis examined the order in which subjects recalled the words in the lists. The optimal strategy for subjects to report the words would be to recall the recency items first followed by the primacy and middle items. Since performance during recall can be influenced by the sequence in which subjects choose to output the word list, we utilized the Relative Index of Priority (RIP) measure (5) to quantify the order in which subjects recalled the words in each list. The first word recalled from a list receives a score of +1, the last word receives a score of -1, and the other items are assigned values that range between these two extremes. In this procedure, output order scores are independent of the number of words recalled.

Each word recalled was assigned a RIP score and the average RIP score for the primacy, middle, and recency portion of each list was computed. Since the purpose of RIP scores is to further explore individual differences in recall, the absence of any impulsivity effects on the recall data led us to collapse across this variable in our analysis of RIP scores. Therefore, a 3 (Caffeine) x 4 (Practice) x 2 (Rate) x 3 (Serial Position) mixed ANOVA was computed on these data separately for males and females.

The analysis of the male data revealed a significant main effect of serial position, $\underline{F}$ (2, 88) = 6.65, $\underline{p} < .01$, indicating that males first output words from the recency portion ($\underline{M}$ = .102) of the lists and then output words from the middle ($\underline{M}$ = -.132) and primacy ($\underline{M}$ = -.139) portions of the lists.

The analysis of the female data revealed significant main effects of serial position, F (2, 114) = 27.7, $p < .01$, and rate, F (1, 57) = 7.27, $p < .01$, along with a rate x serial position interaction, F (2, 114) = 7.40, $p < .01$. These effects indicate that females output words from the recency portion of the curve first, followed by words from the primacy and middle portions of the lists. However, the pattern of RIP scores as a function of serial position varied for the fast (-.298, -.093, .179) and slow rates (-.113, -.190, .203).

DISCUSSION

The primary result of the present study was that caffeine impaired recall for females, but not males. The impaired recall for females was probably not due to caffeine induced differences in encoding strategies, since the effects of caffeine and serial position were additive. Furthermore, caffeine did not influence the order in which females chose to output the words, as indicated by the absence of a caffeine by serial position interaction for the organizational output data. The caffeine by rate interaction suggests that caffeine may be affecting the efficiency with which the information was encoded or manipulated in working memory (3).

One reason for the failure to observe any caffeine effects in males may be that an insufficient number of males were tested to provide a sensitive test of any caffeine effects. However, the analysis of the male data was sensitive enough to detect the standard effects of rate, serial position, and their interaction (3). Furthermore, unlike the female data, the size of the rate difference as a function of caffeine for males showed no hint of an interaction with rate differences of 16.1%, 19.1%, and 17.9% for the 0, 2, and 4 mg/kg dose respectively.

A second reason for the failure to observe any caffeine effects in males may be due to differences in the absolute amount of caffeine received by the males and females. Males weighed more than females and consequently received

more caffeine than females. However, the caffeine dose was adjusted for body weight, and theoretically, each group received equivalent doses of caffeine. It is possible that caffeine may be metabolized at different rates for males and females (6); however, we are unaware of any empirical confirmation of this hypothesis.

Finally, sex differences in the pattern of caffeine effects may be due to sex differences in the self-reported amount of caffeine consumed daily, such that females report consuming an average of 327 mg of caffeine a day while males reported an average daily consumption of 167 mg. However, in a subsequent study, we failed to replicate this sex difference in self-reported caffeine consumption, although females again reported a higher daily consumption rate than males. Although differences in reported caffeine consumption were related to recall performance in the present study, these differences did not influence the effects of caffeine observed. Future work needs to more carefully examine the potential interactive role of acute doses of caffeine and habitual levels of caffeine consumption.

The pattern of caffeine effects observed in the female's data is congruent with the recent theoretical notions of Humphreys and Revelle (10). They argued that arousal should impair performance on tasks that place higher demands on the capacity of working memory. For example, caffeine impaired visual search performance when subjects searched for a 6 letter target but not a 2 letter target (1). When subjects attempt to remember supraspan word lists, as in the present study, working memory capacity is required to access information from long-term memory and simultaneously manipulate information in working memory (rehearsal, organization). The fact that caffeine impaired recall in the present study is congruent with the idea that caffeine impairs performance on tasks that place high demands on working memory (10). The reason why caffeine did not impair female's recall at the fast rate of presentation is unclear.

Possibly, more extensive manipulations of presentation rate will more clearly ellucidate the interactive influence of caffeine and task demands on recall performance.

The effects of caffeine on information processing are probably subtle and complex. If researchers begin to use theoretically motivated tasks with clearly discernible component processes, as in the present study, the specific components of information processing that caffeine influences will become clear.

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Table 1

Demographic Characteristics of Subjects

Level of Impulsivity	High Impulsivity						Low Impulsivity					
Dose of Caffeine	0 mg/kg		2 mg/kg		4 mg/kg		0 mg/kg		2 mg/kg		4 mg/kg	
Sex	M	F	M	F	M	F	M	F	M	F	M	F
N	7	9	7	8	6	9	9	12	9	10	9	12
WAIS-Raw	48.57	49.56	53.14	52.38	52.67	53.44	53.33	51.58	53.89	51.10	53.33	52.08
WAIS-Scaled	12.00	11.44	12.43	11.75	11.83	12.33	12.11	12.00	12.33	11.80	12.22	11.75
Subject's Weight	166.71	138.78	170.86	123.88	174.83	141.33	171.56	148.92	180.22	141.50	174.78	127.33
Impulsivity Scores	7.00	5.66	5.71	6.38	5.33	6.11	2.88	3.17	3.33	2.90	3.11	3.50
Average Daily Self-Reported Average Daily Amount of Caffeine Consumed (mg)	161	333	239	356	108	365	262	308	160	231	97	371

Table 2

Mean Proportion of Words Recalled as a Function of Level of Practice and Serial Position for Females

	Serial Position		
Practice	Primacy	Middle	Recency
Level 1	.582	.370	.706
Level 2	.587	.491	.734
Level 3	.593	.430	.771
Level 4	.576	.530	.763

Table 3

Mean Proportion of Words Recalled as a Function of Caffeine Dose and Rate of Presentation for Males and Females

Males

	Caffeine Dose		
Rate	0 mg/kg	2 mg/kg	4 mg/kg
Fast	.516	.501	.502
Slow	.604	.600	.593

Females

	0 mg/kg	2 mg/kg	4 mg/kg
Fast	.533	.535	.522
Slow	.706	.636	.635

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